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Effect of Neutron Spectra and Multiple Reactions on Transmutation of W and V Alloys

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The effect of neutron spectra depending on the design of compositional structures of a fusion reactor and multiple step reactions in calculation on the transmutation of tungsten, vanadium and V-4Cr-4Ti at the first wall position of a fusion reactor blanket were examined. $Li_2O/Be/H_2O$ and Liq. Li/Be blankets were assumed and FENDL/A2.0 and JENDL3.2 were used as nuclear data sources. As a results of calculation, W was estimated to change to Re, Os and Ir after heavy irradiation. V was also predicted to produce a considerable amount of Cr. The extent of transmutation depends on the neutron spectrum. Estimated transmutations of some nuclides are also affected by nuclear data source. The amount of hydrogen produced through $^{51}V(n,np)^{50}Ti$ for FENDL/A-2.0 was about 4 times higher than for JENDL-3.2.

KEYWORDS: transmutation, simulation calculation, tungsten, vanadium alloy, nuclear data

I. Introduction

Transmutation resulting in change of composition, helium and hydrogen production, and induced activity under neutron irradiation is considered as one of severe problems for first wall materials of fusion reactors. The compositional change and gaseous products lead the degradation of materials and induced activity should be lowered from the viewpoint of reactor and environmental safety. Since the degree of transmutation depends on the neutron spectrum, designs of fusion reactor structures such as blanket and shield must be considered to understand the transmutation behaviors of materials. Recently, high burn-up of some metals such as Mo, Re, W, Ta, V have been predicted under fusion neutron irradiation conditions[1]. In the simulation of transmutation, the number of reaction steps is also important to estimate the exact compositional changes.

In the present paper, the transmutation behaviors of W, V and V-4Cr-4Ti were examined using a simulation code under different blanket systems considering multiple steps of reactions.

II. Calculation Procedures

Neutron spectrum calculation was made using ANISN for the blanket models based on ITER inboard structure designs [2]. The main structures are composed of tungsten armor of 2cm, first wall of 1.5cm, blanket/shield of around 150cm, SUS 316 vacuum vessel, super-conducting magnet, and liquid helium vessel. In the present study, V-4Cr-4Ti was assumed as the first wall material and the composition of blanket/shield materials was changed. Two types of blanket were considered. One blanket is composed of V-4Cr-4Ti, liquid Li and Be (Li blanket). The other one (water blanket) consists of stainless steel, Li_2O with condensed 6Li, Be and water [3]. Nuclear data libraries with 42 energy groups of neutron used for transmutation calculations were FENDL/A2.0 and JENDL3.2. FUSION-40[4] was used for the neutron spectrum calculation. Transmutation calculation of materials was conducted using IRAC[5] code handling step reactions on the basis of neutron spectra obtained by ANISN. In the calculation, maximum steps of the nuclear reaction for tungsten and vanadium isotopes were seven and three, respectively. The neutron wall loading of $1MW/m^2$ was assumed.

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III. Results and Discussion

1. Neuron Spectra at the First Wall of the Blanket

Figure 1 shows the neutron spectra at the first wall for Li blanket and water blanket systems. There is a large difference in neutron flux at low energy region between blanket materials. Especially, in the Li blanket system, the sharp decrease of the neutron flux is observed with

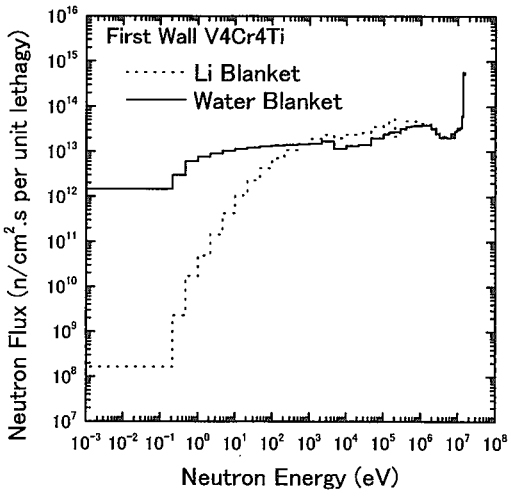

Fig. 1 Neutron spectra at the first wall of the blanket of fusion reactors.

decreasing neutron energy.

Simulation calculations for transmutation of W, V and V-4Cr-4Ti were made under these spectra.

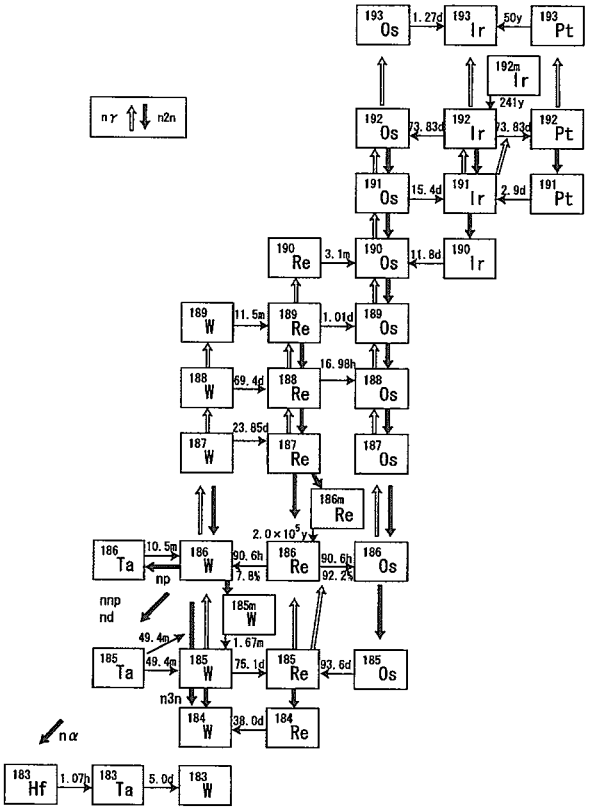

Fig. 2 Seventh step reaction chains of ^{186}W

2 Transmutation of W

Tungsten is composed of 0.135% ^{180}W, 26.4% ^{182}W, 14.4% ^{183}W, 30.6% ^{184}W and 28.4% ^{186}W. The step calculation was made for all these nuclides. In **Fig.2**, the chains of 7 steps reactions for ^{186}W are shown as an example. FENDL/A2.0 is basically used in the calculation since it covers almost all nuclear data including those of radioactive nuclides, which are needed in treating step reactions. At 2nd and the following step reactions, only reactions with cross sections over 100mbarn were considered. The reactions after the second step are mainly (n, γ) and (n,2n).

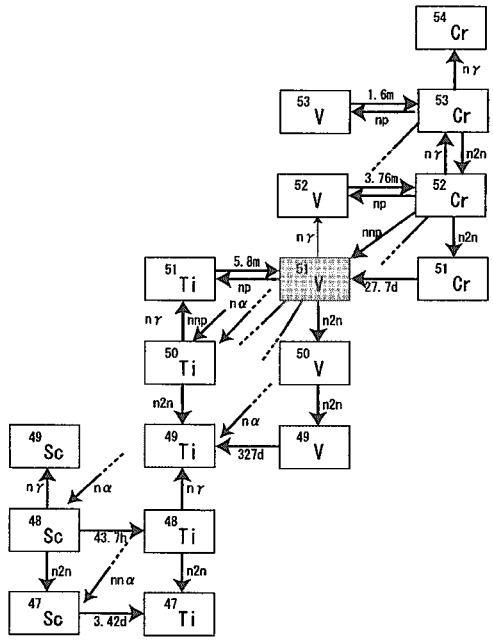

Fig. 3 Third step reaction chains of ^{51}V.

Table 1 shows the effect of number of reaction steps on W transmutation. The W was assumed to be irradiated at the water blanket for 10MW a/m^2. As seen in Fig.2, Re, Os, Ir and Pt are produced by neutron capture reactions. However, even 6th or 7th step reactions are assumed, the amounts of Ir and Pt produced are so small to be ignored.

Table 1 Effect of reaction steps on W transmutation for 10MW a/m^2 irradiation in water blanket system (at%)

Steps	W	Ta	Hf	Re	Os	Ir	Pt	He	H
1	57.14	1.86	0.006	40.99	0.00	0.00	0.00	3.66E-03	8.31E-03
2	56.66	1.84	0.006	39.02	2.46	0.00	0.00	3.64E-03	8.27E-03
3	57.22	1.87	0.006	38.41	2.47	0.00	0.00	3.71E-03	8.42E-03
4	56.88	1.86	0.006	38.48	2.76	0.00	0.00	3.69E-03	8.37E-03
5	57.39	1.88	0.006	37.98	2.74	4.3E-08	0.00	3.72E-03	8.45E-03
6	57.56	1.89	0.006	37.80	2.73	4.1E-08	4.6E-10	3.74E-03	8.48E-03
7	57.62	1.89	0.006	37.73	2.74	4.1E-08	4.5E-10	3.74E-03	8.49E-03

Table 2 Effect of neutron spectrum on W transmutation for 10MW a/m^2 irradiation (%).

Blanket	W	Ta	Hf	Re	Os	Ir	Pt	He	H	Dpa
Li	87.16	1.45	0.005	11.24	0.14	1.2E-09	8.1E-12	3.07E-03	6.97E-03	56.7
Water	57.62	1.89	0.006	37.73	2.74	4.1E-08	4.5E-10	3.74E-03	8.49E-03	51.2

Table 3 Effect of reaction steps on V transmutation for 20MW a/m^2 irradiation in water blanket system (at%)

No. steps	V	Sc	Ti	Cr	He	H
1[1]	93.83	3.4E-05	1.21	3.62	0.087	1.252
2	93.83	3.4E-05	1.20	3.63	0.087	1.252
3	93.81	3.4E-05	1.22	3.63	0.087	1.258

Table 4 Effect of neutron spectrum on V transmutation for 20MW a/m^2 irradiation (at%)

Blanket	V	Sc	Ti	Cr	He	H	dpa
Li	96.70	3.7E-05	1.32	0.53	0.094	1.358	206
Water	93.81	3.4E-05	1.22	3.63	0.087	1.258	183

Table 5 Effect of neutron spectrum on V-4Cr-4Ti transmutation fo 20MW a/m^2 irradiation (at%)

Blanket	V	Ti	Cr	SC	He	H	Mn	Ca	K
As received	91.84	4.25	3.91	0.00E+00	0.000	0.000	0.00E+00	0.00E+00	0.00E+00
Li	88.81	5.42	4.37	6.23E-03	0.104	1.286	4.91E-04	2.61E-03	8.95E-14
Water	86.23	5.28	7.19	5.74E-03	0.096	1.188	2.50E-03	2.39E-03	7.54E-14

Table 2 shows the effect of neutron spectrum on the composition of W after 10MW a/m^2 irradiation. The water blanket contains fair amount of thermal neutrons leading the acceleration of transmutation of W to Re and Os due to neutron capture reaction.

3. Transmutation of V and V-4Cr-4Ti

Transmutation calculation for V was made for 3 steps at maximum as shown in **Fig.3**. The effect of number of reaction steps on the compositional change of V is shown in **table 3** where 20MW a/m^2 of irradiation was assumed. It is hardly to observe the effect of step reactions on the compositional change of V.

The effect of neutron spectrum on the transmutation of V and V-4Cr-4Ti are shown in **table 4 and 5**, respectively.
In the water blanket, about 3.6% Cr and 1.2% Ti are produced by 20MW a/m^2 irradiation while only 0.5% Cr is formed in the Li blanket. In case of V-4Cr-4Ti (V - 3.91at%Cr - 4.25at%Ti), the alloy composition is expected to change to V-7.4Cr-5Ti (V-7.19at%Cr-5.28at%Ti) after 20MW a/m^2 irradiation in the water blanket.

4. Effect of Nuclear Data on H Production

As seen in tables 4 and 5, the amount of hydrogen produced in V is about 10 times higher than helium. It was pointed out that cross section data of ENDF/B-VI on ^{51}V(n,np)^{50}Ti, which FENDL/A2.0 adopted, is about 4 time higher than those of ENDF/B-V and JENDL3.2 [6] as seen in **Fig.4**.

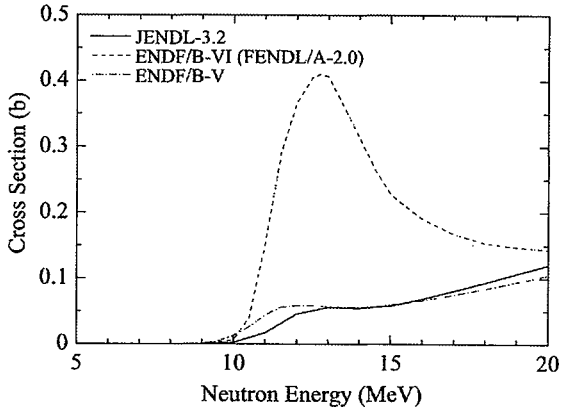

Fig.4 Comparison of ^{51}V(n,np)^{50}Ti cross-section data

Table 6 shows the comparison of hydrogen production from V between FENDL/A2.0 and JENDL3.2 data on ^{51}V(n,np)^{50}Ti after 20MW a/m^2 irradiation. Hydrogen

production of V by JENDL3.2 is about 1/3 of FENDL/A2.0. Since hydrogen production in V is important from the viewpoints of hydrogen inventory and mechanical properties of V, a consistency between nuclear data sources is desired.

Table 6 Effect of nuclear data on H production in V for 20MW a/m^2 irradiation (at%)

Blanket	FENDL/A2.0	JENDL3.2
Li	1.358	0.394
Water	1.258	0.363

IV. Conclusion

Transmutation of W, V and V – 4Cr - 4Ti for V - 4Cr - 4Ti/Li/Be (Li blanket) and SUS316/Li_2O/H_2O (Water blanket) systems were examined by using the simulation calculation code considering multiple step reactions. Conclusions are as follows:

1. Fair amounts of Re and Os are produced especially in water blanket with high thermal neutron flux. However, the composition in W is not largely changed even considering multiple reactions with more than 3 steps.
2. The elements of V and V-4Cr-4Ti transmutations are not clearly affected by multiple step reactions.
3. In water blanket, about 4% Cr can be produced for about 20MW a/m^2 irradiation.
4. Estimation of hydrogen production in V depends on the nuclear data source on $^{51}V(n,np)^{50}Ti$. The amount of hydrogen produced using ENDF/B-VI is about 3 times higher than that for JENDL3.2.

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